**PCT** WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| | | |
|---|---|---|
| (51) International Patent Classification 7 : H04B 1/707 | A1 | (11) International Publication Number: **WO 00/49724**<br>(43) International Publication Date: 24 August 2000 (24.08.00) |

**(21) International Application Number:** PCT/GB00/00556

**(22) International Filing Date:** 17 February 2000 (17.02.00)

**(30) Priority Data:**
9903465.4 17 February 1999 (17.02.99) GB

**(71) Applicant** *(for all designated States except US)*: KINGS COLLEGE LONDON [GB/GB]; Strand, London WC2R 2LS (GB).

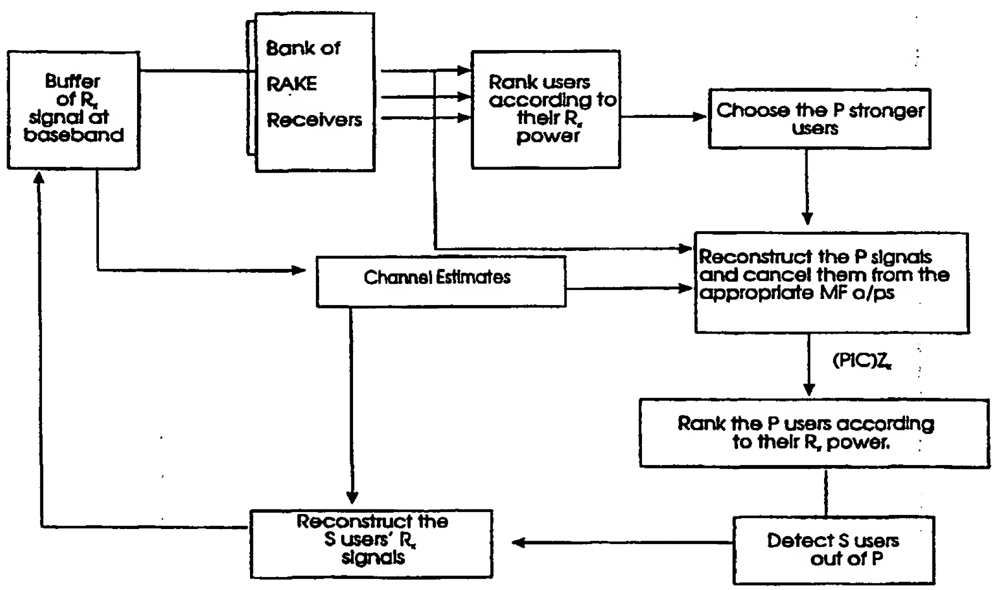
**(72) Inventors; and**
**(75) Inventors/Applicants** *(for US only)*: AGHVAMI, Abdol, Hamid [GB/GB]; 54 Mountfield Road, London W5 2NQ (GB). KOULAKIOTIS, Dimitris [GR/GB]; Kings College London, Strand, London WC2R 2LS (GB).

**(74) Agent:** COHEN, Alan, Nicol; 2 Grove Place, Tatsfield, Nr Westerham, Kent TN16 2BB (GB).

**(81) Designated States:** AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published**
*With international search report.*
*Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*

**(54) Title:** ADAPTIVE HYBRID INTERFERENCE CANCELLATION FOR MULTI RATE USERS




**(57) Abstract**

A method for reducing interference which can be applied to a multi–rate (multi–service) wideband code division multiple access (W–CDMA) which is used in personal mobile communications in which there are users with a high bit rate and users with a lower bit rate and in which the HIC configuration for the high bit rate users is different from the HIC configuration of the low bit rate users and in which method first the higher bit rate users have their interference reduced by hybrid interference cancellation (HIC) and then the interference between the other lower bit rate users reduced by HIC.

***FOR THE PURPOSES OF INFORMATION ONLY***

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **AL** | Albania | **ES** | Spain | **LS** | Lesotho | **SI** | Slovenia |
| **AM** | Armenia | **FI** | Finland | **LT** | Lithuania | **SK** | Slovakia |
| **AT** | Austria | **FR** | France | **LU** | Luxembourg | **SN** | Senegal |
| **AU** | Australia | **GA** | Gabon | **LV** | Latvia | **SZ** | Swaziland |
| **AZ** | Azerbaijan | **GB** | United Kingdom | **MC** | Monaco | **TD** | Chad |
| **BA** | Bosnia and Herzegovina | **GE** | Georgia | **MD** | Republic of Moldova | **TG** | Togo |
| **BB** | Barbados | **GH** | Ghana | **MG** | Madagascar | **TJ** | Tajikistan |
| **BE** | Belgium | **GN** | Guinea | **MK** | The former Yugoslav Republic of Macedonia | **TM** | Turkmenistan |
| **BF** | Burkina Faso | **GR** | Greece | | | **TR** | Turkey |
| **BG** | Bulgaria | **HU** | Hungary | **ML** | Mali | **TT** | Trinidad and Tobago |
| **BJ** | Benin | **IE** | Ireland | **MN** | Mongolia | **UA** | Ukraine |
| **BR** | Brazil | **IL** | Israel | **MR** | Mauritania | **UG** | Uganda |
| **BY** | Belarus | **IS** | Iceland | **MW** | Malawi | **US** | United States of America |
| **CA** | Canada | **IT** | Italy | **MX** | Mexico | **UZ** | Uzbekistan |
| **CF** | Central African Republic | **JP** | Japan | **NE** | Niger | **VN** | Viet Nam |
| **CG** | Congo | **KE** | Kenya | **NL** | Netherlands | **YU** | Yugoslavia |
| **CH** | Switzerland | **KG** | Kyrgyzstan | **NO** | Norway | **ZW** | Zimbabwe |
| **CI** | Côte d'Ivoire | **KP** | Democratic People's Republic of Korea | **NZ** | New Zealand | | |
| **CM** | Cameroon | | | **PL** | Poland | | |
| **CN** | China | **KR** | Republic of Korea | **PT** | Portugal | | |
| **CU** | Cuba | **KZ** | Kazakstan | **RO** | Romania | | |
| **CZ** | Czech Republic | **LC** | Saint Lucia | **RU** | Russian Federation | | |
| **DE** | Germany | **LI** | Liechtenstein | **SD** | Sudan | | |
| **DK** | Denmark | **LK** | Sri Lanka | **SE** | Sweden | | |
| **EE** | Estonia | **LR** | Liberia | **SG** | Singapore | | |

# ADAPTIVE HYBRID INTERFERENCE CANCELLATION FOR MULTI RATE USERS

The present invention relates to a method for reducing interference in Wireless Telecommunications Systems and in particular it relates to a method for reducing interference which can be applied to a multi-rate (multi-service) wideband code division multiple access (W-CDMA) which is used in personal mobile communications.

Interference cancellation is used to reduce the interference between two or more signals.

W-CDMA will be able to support more than one service in a single carrier e.g. a 5 MHz carrier and this can cause interference among users of the same service and between users of one service and users of the other services.

Interference can occur when there are users with a high bit rate and a low bit rate using the same bandwidth. In these circumstances there will be interference amongst users of the same service (for both high and low bit rate users) and also considerable interference by the high bit rate users on the low bit rate users. This can occur when there are video signals which have a high bit rate and voice signals which have a lower bit rate using the same bandwidth.

Normally the spreading sequence (codes) are designed in such a way that

$\int_{0}^{T_b} |c_k(t)|^2 dt = 1$, ( where $c_k(t)$ represents the user's code). This is reflected in the different power spectrum density (PSD) of different services. Using a fixed bandwidth, the lower the processing gain (PG), i.e. higher bit rate, the more powerful (higher PSD) interferer a user is to other, lower bit rate users (higher PG) so that users

of lower bit rate services will experience severe interference from users of higher bit rate services.

It is known to use a successive interference cancellation (SIC) scheme to reduce interference between users as described in "Analysis of a Successive Interference Scheme in a DS/CDMA System" IEEE Journal on Selected Areas in Communications, Vol 12, No. 5 pp 796-807 June 1994 by P. Patel, J Holtzman, however this technique can involve a long delay for the detection/ cancellation of all user and, assuming a one bit delay is required for one loop, then the total delay for the detection/ cancellation of K users is K bits. The scheme is such that the first users detected experience either no, or a small reduction in MUI as, for example, the first user detected experiences no interference reduction and the second user only that due to the cancellation of the first user etc. so only the last user will experience complete MAI cancellation.

However, due to the unequal amount of interference seen by each user, users cancelled initially have different signal to noise ratio (S/N ratio) and thus bit error rate (BER), than users cancelled later in the interference cancellation process. This involves the need for some sort of power control that will ensure that all users have the same S/N ratio and thus BER.

Another interference cancellation scheme is parallel interference cancellation (PIC), however this involves high complexity as each user regenerates/cancels a replica of its signal K-1 times so that the total number of regenerations/cancellations is K(K-1) and the regeneration process of all interferences includes users that are weak and thus unreliable. In order to avoid this conventional PIC requires either fast power control (in order to compensate for the near/far effect) and/or multistage.

This is described in "Improved Parallel Interference Cancellation for CDMA" by D. Divsalar et al, IEE Trans. On Comms. Vol. 46 No2 pp 258-268 February 1998.

We have now devised an interference scheme which reduces these problems.

According to the invention there is provided a method for reducing interference between users of a carrier signal in which there are users with a high bit rate and users with a lower bit rate in which first the higher bit rate users have their interference reduced by hybrid interference cancellation (HIC) and then the interference between the other lower bit rate users reduced by HIC.

The HIC configuration for the high bit rate users is different from the HIC configuration of the low bit rate users and the method of the invention takes advantage of this flexibility; this is not possible with PIC and SIC.

The principal idea behind HIC is that instead of cancelling all K users either in series or parallel there is cancellation partially in series and partially in parallel. HIC is described in D. Koulakiotis, A.H. Aghvami, "Evaluation of a DS/CDMA Multiuser Receiver Employing a Hybrid form of Interference Cancellation in Rayleigh Fading Channels", IEEE, Communication Letters, Vol. 2, No 3, pp.61-63, March 98.
D. Koulakiotis, A.H. Aghvami, "Effect of Imperfect Amplitude Estimation on the Performance of Hybrid Interference Cancellation", ICC'98, Atlanta, USA, pp.1571-1575, June 1998.
D. Koulakiotis, A.H. Aghvami, "Hybrid Interference Cancellation, a Multiuser Detection Scheme for W-DS/CDMA Systems", ICT'98, Porto Carras, Greece, Vol II, pp.52-56, June 1998.

Taking the higher bit rate users and the lower bit rate users separately this can be expressed as K-P-S where K is the total number of users in the category and the number cancelled at the PIC and SIC stage is expressed by P and S respectively.

The signals selected for partial PIC are preferably the "most reliable users" (users whose interferences can be regenerated most correctly) and this ensures that most of the interference will be cancelled between the P users and the partial P cancellation is substantially accurate.

Thus, for a 10-5-2 configuration the number of users per loop at the buffer with the $R_x$ signal will be 10,8,6,4,2, while at the partial PIC stage there will be 5,5,5,4,2 users respectively, at the end of which 2 users will be cancelled per loop.

According to the UMTS Specifications (concept Group Alpha-Wideband Direct – Sequence CDMA, Part 1: System Description, Performance Evaluation, ETSI SMG2#23, Bad Salzdetfurth, Germany, October 1997) the number of higher bit rate users will be small.

A block diagram of an HIC system is shown in fig. 1 and such a system is applied to the higher bit rate users and then applied to the lower bit rate users.

The advantages of this hybrid interference cancellation (HIC) system over PIC and SIC is that the system will have better performance because interference cancellation takes place at two places (1. partial PIC and 2. cancellation at the end of the loop from the received compound signal). The selection, at 1, of the "most reliable users" ensures that most of the interference will be cancelled among the P users, the cancellation of more than one user at the time ensures that the total delay is not high, unlike SIC and, in addition, at high bit rates the limitation due to delay is partially alleviated. The repetitive partial PIC requires fewer computations than the equivalent one stage PIC and the K-P-S configuration is flexible so that it enables there to be a trade off between complexity and BER performance.

By carrying out HIC on the higher bit rate users followed by carrying out HIC on the lower bit rate users interference between the higher bit rate users and lower bit rate users and amongst the different bit rate users is reduced.

The position where the interference cancellation takes place is optional, the regenerated signals can be cancelled from the received signals at the baseband or the cross correlations between the cancelled and the remaining users can be cancelled from matched filter outputs. Fewer operations are required in the latter case, reducing complexity as the former requires re-processing through matched filters. However cancelling the interference at the baseband improves the detection of users auto-correlation peaks thus improving delay estimation.

The use of HIC is exemplified with reference to the comparison with various configurations and PIC and SIC and the results shown in figs 2 to 5.

In the figures, the BER performance of five configurations of HIC (10-5-5, 10-5-2, 10-4-4, 10-4-3 and 10-4-2) is assessed, along with PIC and SIC and a version of SIC with only six out of ten cancellations, in order to compare all the schemes based on similar delay requirements. All the results are related to the upper bound (UB) i.e. the matched filter receiver and also the lower bound (LB) i.e. the single user case.

Figs. 2, 3 and 4 depict the simulation results for processing gains (PG) of 19, 25 and 47 respectively, in fig. 5 there are 10 users and PG of 49. It is clear that HIC performs much better than either SIC and PIC and for HIC 10-5-2 is the best. In general the more users at the P stage and the fewer at the S stage the better the result so 10-10-1 (K-K-1) should give the best performance however such as system is not feasible in a single service W-CDMA environment due to its increased complexity. In fig. 4 it can be seen that although PIC and SIC are above the lower bound the HIC configurations, especially the 10-4-2 is very close to it and, in particular for low Eb/No the two performances almost match.

In the case of complexity in SIC, each user is regenerated/cancelled once whilst, for PIC, each user has to regenerate its signal and cancel it from the remaining K-1 users. The process of regeneration and cancellation of a user is more complex than the one of ranking.

It can be shown that for K equal to 10 users the results in table 1 are obtained.

Table 1

| SIC | 10-4-4 | 10-4-3 | 10-5-5 | 10-4-2 | 10-5-2 | PIC |
|---|---|---|---|---|---|---|
| 9 | 34 | 45 | 45 | 58 | 82 | 90 |

As can be seen, SIC requires the smallest number and PIC the largest number, among HIC 10-5-2 offers the best BER at the expense of increased complexity, however 10-4-3 and 10-4-4 require half or less but give very good BER performance.

A second measure of complexity is the number of user rankings which have to be done. For PIC user rankings are not required and the results for 10 users are shown in Table 2.

Table 2

| PIC | 10-4-4 | 10-4-3 | 10-5-5 | 10-4-2 | 10-5-2 | SIC |
|---|---|---|---|---|---|---|
| - | 25 | 28 | 35 | 48 | 51 | 54 |

As can be seen SIC requires the largest number and HIC 10-4-4 and 10-4-3 require numbers which are nearly half the maximum required by SIC. Overall PIC is the most complex scheme and HIC 10-4-4 and 10-4-3 provide two affordable complex solutions.

In practice W-CDMA will be expected to use cascade IC schemes so two or more stages will be used and the computations will be increased by the number of stages.

Where there are users in a bandwidth which can be divided between two services a high bit rate (with H users) and a low bit rate (with L users) the number of users K = H + L.

The cancellation of interference amongst the high bit rate users is carried out using HIC and then cancellation of the interference amongst the low bit rate users is carried out using HIC.

The cancellation of the signals (interference) of the high bit rate users should be as complete as possible, otherwise there is the risk that the residual high bit rate interference will degrade the performance of the interference cancellation process during cancellation among the low bit rate users. As there will be a low number of high bit rate users, cancellation of the signals of the high bit rate users can be carried out using a complex HIC configuration e.g. H-H-1, or a less complex configuration but still having high performance capabilities. During this stage of detection/cancellation of high bit rate users, interference from the low bit rate users can be considered as noise.

The HIC configuration chosen to reduce the interference among the low bit rate users can be selected as specified above.

In the case where the total number of users K = H + L, where H is the number of high bit rate users and L is the number of low bit rate users, then the method can be applied by firstly using an HIC with the best BER among HIC configurations as referred to above e.g. H-H-1, to cancel the signals (interference) of the high bit rate users and then applying HIC e.g. L-P-S to cancel the interference among the low bit rate users.

This is illustrated in the block diagram shown as fig. 6.

The invention is exemplified in fig. 7 in which there are 9 low bit rate users and 1 high bit rate user. Simulations are performed for both cases of 4-arm and 6-arm RAKE receiver

(1) in the case when all users (high + low bit rate) use a conventional matched filter detector.

(2) in the case where a matched filter detector is used for the low bit rate users but interference cancellation is applied on the high bit rate user.

Results are repeated for the case of 4-arm RAKE receiver

(3) in the case when all users use the conventional matched filter detector

(4) in the case where a matched filter detector is used for the low bit rate users but interference cancellation is applied on the higher bit rate user.

This illustrates the advantage of cancelling the high bit rate users that cause severe interference to the low bit rate users. Even when there is only one high bit rate user there is a substantial improvement in the average BER when this is cancelled. Interference cancellation is not applied amongst the low bit rate users in this example.

Claims

1. A method for reducing interference between users of a carrier signal in which there are users with a high bit rate and users with a lower bit rate in which first the higher bit rate users have their interference reduced by hybrid interference cancellation (HIC) and then the interference between the other lower bit rate users reduced by HIC.

2. A method as claimed in claim1 in which the signals selected for partial PIC are the most reliable users as herein defined.

3. A method as claimed in claim 1 or 2 in which the regenerated signals are cancelled from the received signals at the baseband.

4. A method as claimed in claim 1 or 2 in which the cross correlations between the cancelled and the remaining users are cancelled from matched filter outputs.

5. A method as claimed in any one of the preceding claims in which the cancellation of the signals of the high bit rate users is substantially complete

6. A method as claimed in claim 5 in which the cancellation of the signals of the high bit rate users is carried out using a complex HIC configuration.

7. A method as claimed in any one of the preceding claims in which the total number users is $K = H + L$, where H is the number of high bit rate users and L is the number of low bit rate users and (i) using an HIC with the best BER among HIC configurations to cancel the signals of the high bit rate users and then (ii) applying HIC to cancel the interference among the low bit rate users.

8. A method as claimed in claim 7 in which in which the signals of the high bit rate users are cancelled using a H-H-1 configuration and then applying L-P-S to cancel the signals among the low bit rate users.

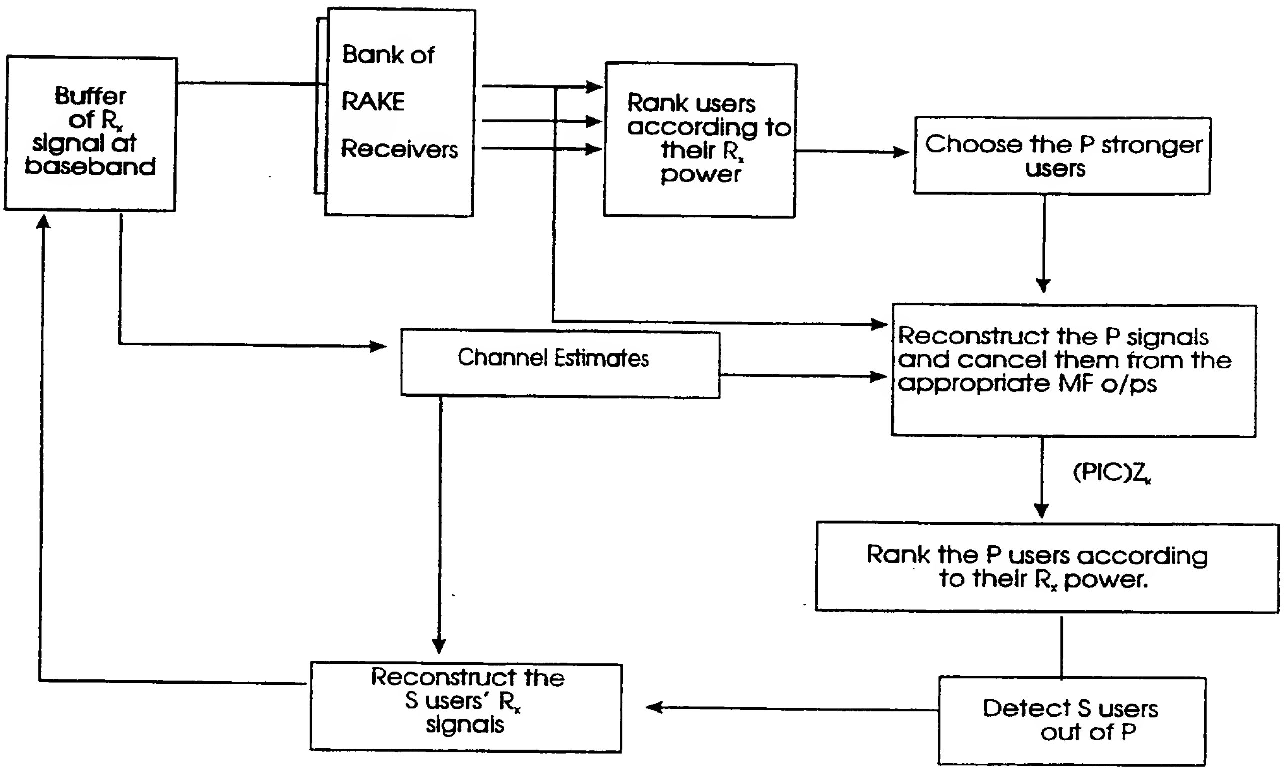

Buffer of $R_x$ signal at baseband
Bank of RAKE Receivers
Rank users according to their $R_x$ power
Choose the P stronger users
Reconstruct the P signals and cancel them from the appropriate MF o/ps
Channel Estimates
(PIC)$Z_x$
Rank the P users according to their $R_x$ power.
Reconstruct the S users' $R_x$ signals
Detect S users out of P

Fig. 1

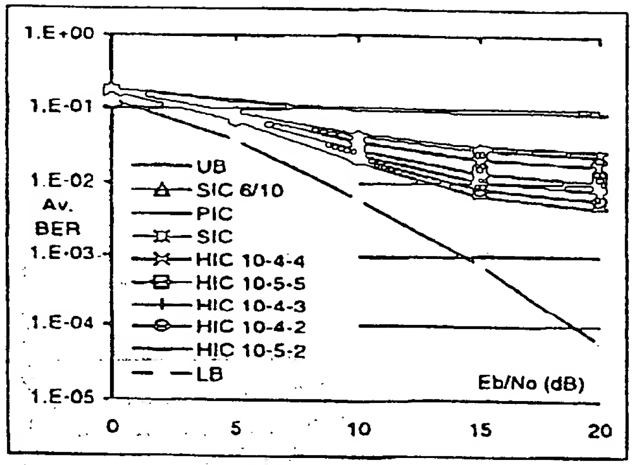



Fig. 2

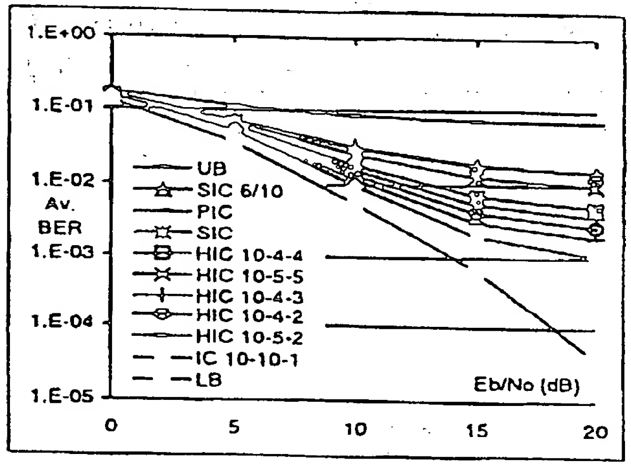



Fig. 3

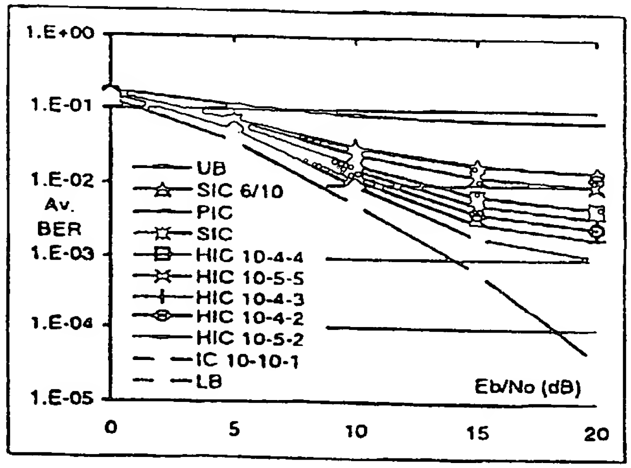



Fig. 4

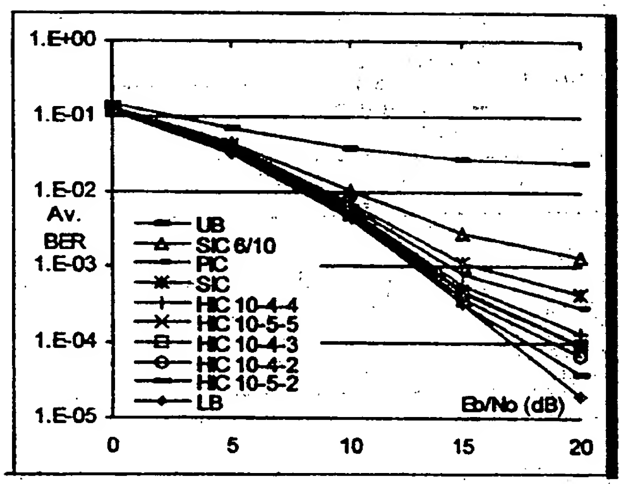

1.E+00
1.E-01
1.E-02
Av. BER
1.E-03
1.E-04
1.E-05
0
5
10
15
20
Eb/No (dB)
UB
SIC 6/10
PIC
SIC
HIC 10-4-4
HIC 10-5-5
HIC 10-4-3
HIC 10-4-2
HIC 10-5-2
LB

Fig. 5

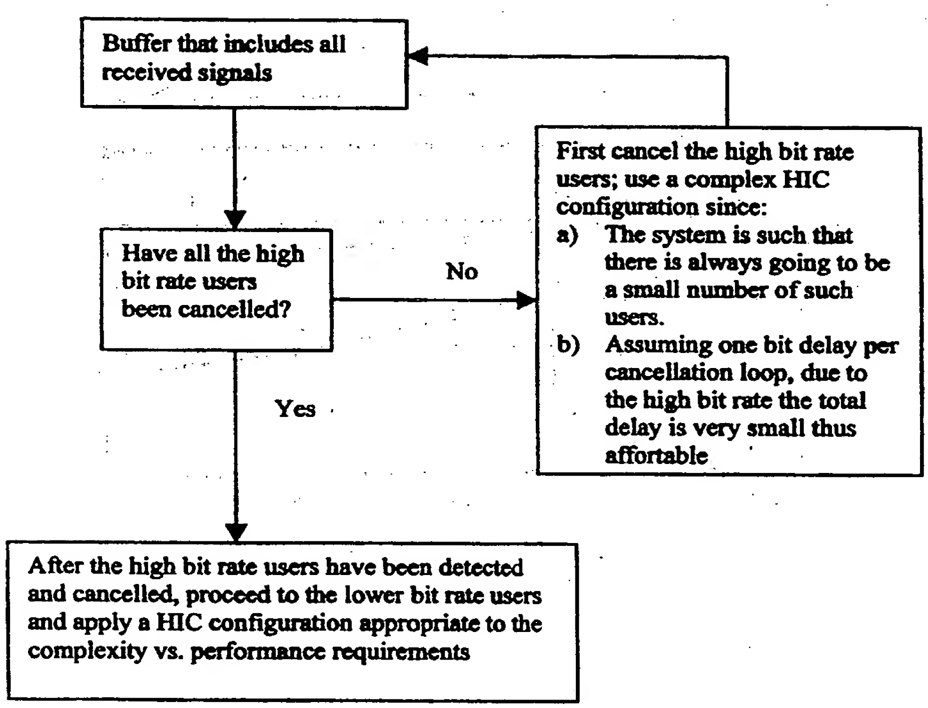

Buffer that includes all received signals
Have all the high bit rate users been cancelled?
No
First cancel the high bit rate users; use a complex HIC configuration since:
a) The system is such that there is always going to be a small number of such users.
b) Assuming one bit delay per cancellation loop, due to the high bit rate the total delay is very small thus affortable
Yes
After the high bit rate users have been detected and cancelled, proceed to the lower bit rate users and apply a HIC configuration appropriate to the complexity vs. performance requirements

Fig. 6

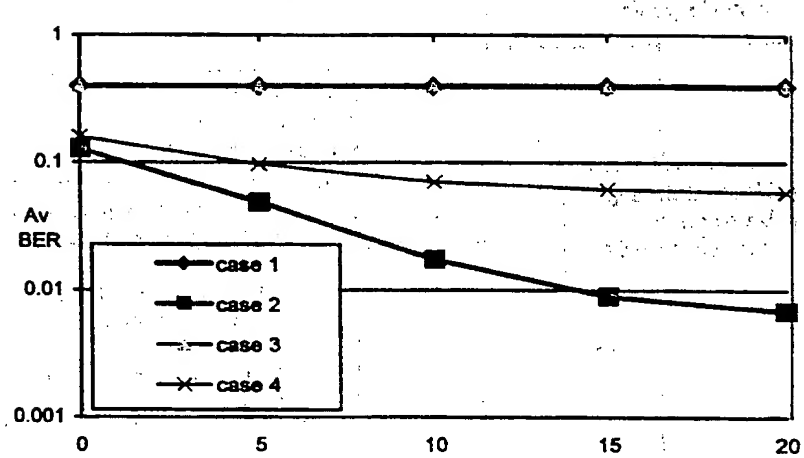



Fig. 7

# INTERNATIONAL SEARCH REPORT

Inter   nal Application No
PCT/GB 00/00556

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | OJANPERA T ET AL: "Qualitative comparison of some multiuser detector algorithms for wideband CDMA" IEEE VEHICULAR TECHNOLOGY CONFERENCE,XX,XX, vol. 1, 1998, pages 46-50-50voll, XP002126104 page 46, right-hand column, line 1 - line 20 page 47, left-hand column, line 37 -right-hand column, line 2 page 49, right-hand column, line 45 -page 50, left-hand column, line 31 —— -/-- | 1,2,5 |

[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 28 June 2000 | 10/07/2000 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016 | Larcinese, A |

1

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| P,X | WIJTING C S ET AL: "Groupwise serial multiuser detectors for multirate DS-CDMA" 1999 IEEE 49TH VEHICULAR TECHNOLOGY CONFERENCE (CAT. NO.99CH36363), 1999 IEEE 49TH VEHICULAR TECHNOLOGY CONFERENCE. MOVING INTO A NEW MILLENIUM, HOUSTON, TX, USA, 16-20 MAY 1999, pages 836-840 vol.1, XP002141307 1999, Piscataway, NJ, USA, IEEE, USA ISBN: 0-7803-5565-2 page 836, left-hand column, line 1 -page 837, right-hand column, line 10 page 837, right-hand column, line 29 -page 838, left-hand column, line 3 | 1,2,5 |
| A | KOULAKIOTIS D ET AL: "EVALUATION OF A DS/CDMA MULTIUSER RECEIVER EMPLOYING A HYBRID FORM OF INTERFERENCE CANCELLATION IN RAYLEIGH-FADING CHANNELS" IEEE COMMUNICATIONS LETTERS,US,IEEE SERVICE CENTER, PISCATAWAY,US, vol. 2, no. 3, 1 March 1998 (1998-03-01), pages 61-63, XP000751853 ISSN: 1089-7798 cited in the application the whole document | 1-8 |

1

This Page Blank (uspto)